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# (54) X-ray tube with a transmission anode

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(56) Documents cited:
**EP-A-0,432,568 US-A-3,683,223**
**US-A-3,894,239 US-A-3,999,096**

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## Description

The invention relates to an X-ray tube with a transmission anode, which comprises a target layer which is struck by electrons in the operating condition and consists of one or more metals of high atomic number, and also comprises a carrier layer which is connected to the target layer and consists of one or more substances of low atomic number.

Such X-ray tubes are disclosed - for example in DE-A-2,729,833, in US-A-2,090,636 and in US-A-3,894,239. There are contradictory requirements for the thickness of the two layers. On the one hand, the target layer should be as thick as possible, in order to convert the striking electrons into X-ray quanta in as high as possible a percentage. On the other hand, this layer must be as thin as possible, in order to weaken the X-ray quanta produced therein as little as possible. The carrier layer must on the one hand be thin enough to weaken the exiting X-rays as little as possible and, on the other, thick enough to ensure mechanical stability and removal of the thermal energy produced in the target layer.

No doubt because of these contradictory requirements, the said X-ray tubes - in each case for a voltage range between 50 and 500 kV, which is important for medical, but also for industrial testing and examinations - have generally failed to gain much entry into practice. X-ray tubes with anodes, in which the X-rays are emitted from the side of the anode on which the electrons strike, are used for these purposes. In the following, these anodes are therefore also termed reflection anodes.

In all X-ray tubes, in the voltage range up to 500 kV only a small portion of the electrical energy applied is converted into X-radiation; the rest of the energy consumed results in heating of the anode. Of the X-radiation produced, again only a small fraction is used as a useful beam of rays outside the X-ray tube.

The object of the present invention is to construct an X-ray tube of the kind mentioned at the beginning whose operating voltage lies in the range between 50 kV and 500 kV, so that with the electrical energy in the useful beam of rays applied for operation of the X-ray tube more X-radiation is produced than in an X-ray tube with reflection anode. This object is accomplished by the measures indicated in the claim.

The invention is based upon the knowledge that the intensity of X-radiation is very strongly dependent upon the angle enclosed by the emitted X-radiation relative to the direction of the electrons. With disregard of weakening by the target, a pronounced intensity maximum is produced on the surface of a cone whose center line is formed by the direction of the electron beam producing the X-rays. The angle of beam spread of this cone is dependent upon the operating voltage, specifically, the higher the operating voltage, the smaller the angle of beam spread. For an operating voltage of 60 kV, half the angle of beam spread of the cone with maximum intensity is about 40°, and for an operating voltage of 500 kV, about 10°.

The invention makes use of this knowledge in that it appropriately selects the angle between the useful beam of rays, i.e., the portion of X-radiation used outside the X-ray tube, and the direction of incidence of the electrons producing the X-radiation.

As a rule, the useful beam of rays has in at least one direction an angle of beam spread differing from zero. In this case, the angle between an X-ray in the center of the

useful beam and the direction of incidence of the electrons must be selected as indicated in the claim.

In previously known X-ray tubes with a transmission anode, the useful beam as a rule travels in the prolongation of the electron path, i.e., the angle θ is zero.

However, there are also X-ray tubes with a transmission anode in which the angle θ differs from zero. Thus, US-A-3,894,239 discloses a rotary-anode X-ray tube with a transmission anode in which an electron beam strikes a target layer approximately perpendicularly, which target layer is inclined approximately 80° with respect to the X-ray exit window. In this way, the continuous bremsstrahlung spectrum produced in the target layer is supposed to be weakened substantially more than the fluorescent radiation produced in the target layer.

In addition, in Fig. 7 of DE-A-2,729,833 is described an X-ray tube with an annular anode, in which the X-radiation is produced by means of two groups of cathodes distributed on the periphery of the anode, which are situated on either side of a central plane running through the emitter. This results in an angle θ of 45° in each instance.

In none of these printed sources is the fact used that the X-radiation in an angular range between 15° (at high tube voltages) and 40° (at low tube voltages) is especially intensive.

Lastly, WO-A-92/03837 discloses an X-ray tube with a reflection anode, in which the electrons strike the anode at an angle of 10° (instead of usually 70° - 90°) and in which the useful beam runs at an angle of 5° - 15° with relation to the anode. However, there, the X-ray exit window may heat up strongly due to emission electrons.

In development of the invention, it is provided that the weight w of the target layer per unit of surface area essential for X-radiation yield - expressed in grams/$cm^2$ - at least approximately satisfies the relation:

$$w = 1.08 \cdot 10^{-6} \cdot (A/Z)^{2.5} \cdot U^{1.6} \cdot \cos \beta,$$

where A is the relative atomic mass and Z the atomic number of the metal of the target layer, U is the operating voltage in kV for which the X-ray tube is designed, and β is the angle enclosed by the direction of incidence of the electrons relative to the normal to the target layer.  For an X-ray tube with a target layer of tungsten, this gives, for an operating voltage U = 100 kV, a mass per unit of surface area of 0.017 g/$cm^2$ and a thickness of 8.6 μm (for β = 0°).

The invention can be used in a variety of X-ray tubes for a variety of applications. According to a preferred refinement of the invention, it is provided that it be designed as a rotary-anode X-ray tube and that the target layer (for example of tungsten and/or rhenium) lie on the surface of a truncated cone, which with the direction of the X-rays used outside the X-ray tube encloses an angle that is smaller than the angle that exists between this direction and the direction of the incident electrons.  There, the anode has the shape of a dish symmetrical with its axis of rotation, whose inner surface provided with the target layer is turned toward the electron-emitting electron source and whose beam of useful rays preferably is emitted from the surface at an angle of 90° to the axis of rotation.

The invention is explained in detail below with reference to the drawing, wherein:

Fig. 1 shows a basic diagram of a portion of a transmission anode and

Fig. 2, a rotary-anode X-ray tube with a transmission anode according to the invention.

The transmission anode shown in Fig. 1 comprises a target layer 1 of a metal having a high atomic number, which is mounted on a carrier layer 2 of a substance having a low atomic number. The target layer 1 may consist for example of tungsten or rhenium or of an alloy of these metals; other metals suitable for the target layer 1 are platinum or thorium. The carrier layer 2 may consist of graphite or beryllium and have a thickness such that, on the one hand, sufficient mechanical stability is produced and, on the other hand, the X-radiation is weakened as little as possible.

The arrow 3 designates an electron beam, which strikes the target layer 1 at an angle $\beta$ to the normal. This produces X-radiation, which spreads to a sphere around the point of impact. Theoretical and experimental studies, however, have shown that if weakening by the target layer is disregarded, the X-radiation, which spreads to the surface of a cone (with its tip in the point of electron impact and its axis of symmetry parallel to the direction of the electron beam) at a given angle of beam spread $\theta$, has the greatest intensity. The upper borderline ray 4a and the lower borderline ray 4b of this cone are shown in Fig. 1.

Half the angle of beam spread $\theta$ of this cone depends upon the operating voltage, where the following table approximately applies:

| U/kV | 60 – 100 | 100 – 150 | 150 – 200 | 200 – 350 | 350 – 500 |
|---|---|---|---|---|---|
| θ | 40° - 35° | 35° - 30° | 30° - 25° | 25° - 20° | 20° - 15° |

Therefore, the X-ray tube must be constructed so that the direction of the useful X-ray beam coincides with the direction of one of the rays on the surface of the cone. The X-radiation produced in the target layer can then run at a variety of angles to the planes of the layer, the drawing showing the smallest angle $\alpha_1$ and the greatest angle $\alpha_2$. These angles satisfy the following relations:

$$\alpha_1 = 90° - \beta - \theta \quad (1)$$

$$\alpha_2 = 90° - \beta + \theta \quad (2)$$

The optimal mass of the target layer per unit of surface area for radiation yield is calculated approximately according to the relation

$$w = 1.08 \cdot 10^{-6} \cdot (A/Z)^{2.5} \cdot U^{1.6} \cdot \cos \beta \quad (3)$$

There, A is the relative atomic mass (atomic weight) and Z the atomic number of the metal of which the target layer consists. $\beta$ is the angle of incidence of the electrons, i.e., the angle that the direction of the beam of electrons 3 forms with the normal to the target layer. When the target layer consists of an alloy of two or more metals, the mass of the target layer per unit of surface area is calculated in that for each metal of the alloy the value w is calculated according to the relation (3) and the calculated values summed weighted according to the respective portion of alloy.

When the direction of exit of the rays is selected according to the table and the thickness of the target layer is sized according to the relation (3), - at like tube voltage and at like tube current - the intensity of X-radiation in the useful x-ray beam is significantly greater than in an X-ray tube with reflection anode, in which the angle between the direction of incidence of electrons and the direction of X-ray exit is approximately 90°. The greater the tube voltage, the more pronounced the intensity.

However, if the X-ray tube is operated at a voltage other than that for which it is designed, these intensity advantages decrease.

A rotary-anode X-ray tube with a transmission anode according to the invention is shown in Fig. 2 as an exemplary embodiment. The X-ray tube comprises a tube bulb 5 of glass, in which is situated a cathode arrangement 6 and an anode arrangement 7. The anode arrangement comprises a transmission anode 2, which is attached in known fashion to a rotor 8, which is seated rotating in the interior of the X-ray tube. The rotor is driven by a stator, not shown in Fig. 2, placed outside the glass bulb.

The transmission anode comprises a supporting member 2 of graphite and has a dish or plate shape open toward the cathode arrangement 6. In the region of the transmission anode swept by the beam of electrons 3 from an electron emitter attached to the cathode arrangement 6, a target layer 1 of rhenium is mounted on the supporting member 2. When the X-ray tube is intended for purposes of computed tomography and accordingly is designed for an operating voltage of 150 kV, and when the electron beam 3 strikes the layer at an angle of 40° to the normal direction, the mass of this layer, referred to unit of surface area per relation (3), is 0.024 g/cm$^2$. This is obtained by an 11.5 μm-thick rhenium layer.

The X-ray tube is situated in the interior of a housing, of which a portion of the housing wall 10 is shown only on the right-hand side in Fig. 2. The housing wall comprises a coating of a material absorbing X-radiation, for example lead of sufficient thickness. An X-ray exit window 11 of a material transparent to X-radiation, for example of aluminum, is provided only at the level of the target layer, so that useful radiation can exit only in this region. The useful radiation then travels perpendicular to the axis of

rotation at an angle of 30° to the direction of the electron beam. In use for CT examinations, an almost plane fan-shaped beam of rays perpendicular to the plane of the drawing of Fig. 2 is blocked. In this case, the principal direction of extension of the X-ray exit window likewise runs perpendicular to the plane of the drawing.

Although the invention has been explained above with reference to a rotary-anode X-ray tube with a glass bulb for medical examinations, the invention is alternatively applicable in other embodiments. For example, instead of a rotary anode, a stationary anode may be used. Instead of an X-ray tube with glass bulb, an X-ray tube with metal bulb, in which the cathode and/or anode are connected with the metal bulb by means of insulators, may alternatively be used. The X-ray tube may alternatively be used for nondestructive testing in the industrial field; especially high efficiency is obtained in the range of tube voltages used for these purposes (200 - 500 kV).

*[Claims in English and German]*